NASA Earth Science Division
Applied Science Program
SWOT Mission

SWOT Applications Plan

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swot.jpl.nasa.gov/applications

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1. Introduction

The Surface Water and Ocean Topography (SWOT) Mission is being jointly developed by NASA and CNES, with contributions from the Canadian Space Agency (CSA) and United Kingdom Space Agency (UKSA). The SWOT mission, along with the airborne concept-validation project, AirSWOT, would provide valuable data and information that would benefit society in two critical areas; freshwater on land, and the oceans' role in climate change. It would fulfill important observations of the amount and variability of water stored in global lakes, reservoirs, wetlands, and river channels and would support derived estimates of river discharge. SWOT would also provide critical information necessary for water management, particularly in international hydrological basins.

According to the new capabilities and performances of the SWOT mission, there is a need to coordinate information and deliver data to users and also to realize new developments that will leverage new applications. A joint preparatory program is therefore essential.

NASA's Earth Science Mission Directorate Applied Sciences Program (ASP) has designated *Applications Leads* for early phase missions identified in the NRC Decadal Survey[1] to identify to provide an applications plan for the mission from development through operations phases. This application plan has been jointly written between NASA and CNES.

In order to build broad support for and awareness of the valuable data products that would be produced from the mission, the SWOT Deputy Program Applications Leads have worked with the SWOT Applications Working Group (SAWG) and the Science Definition Team (SDT) to identify optimal user communities and engaged users from operational agencies who will become "Early Adopters" of simulated hydrology and oceanographic mission data sets, and of regional AirSWOT data products.

This Plan outlines the applications-oriented Project and international partner efforts which are planned for the SWOT mission, outlines an approach to engaging the SWOT and AirSWOT end user community, and describes the methods to be used to achieve a successful and relevant program.

2. SWOT Mission Description

NASA and CNES along with their partners, the CSA and the UKSA (pending final partnership agreements) are developing SWOT to accomplish the first global survey of

[1] http://www.nap.edu/catalog.php?record_id=11820

Earth's surface water. The SWOT mission with its wide swath altimetry technology would be able to cover most of the world's ocean and major freshwater bodies with repeated high resolution elevation measurements, providing observations of fine details of the ocean's surface topography, and measuring how water bodies change over time.

The SWOT mission concept is comprised of the SWOT spacecraft, the Project and Program offices, and the Science Definition Team (SDT) that was selected by NASA, CNES and the CSA to guide science aspects of the mission.

SWOT is scheduled to launch in late 2020 with newly developed wide-swath altimetry technology, the Ka-band Radar Interferometer (KaRIn) instrument. It would be a means of covering much of the world's oceans and freshwater bodies with repeated elevation measurements. The measurement technique uses radar interferometry to obtain wide-swath measurements of water elevation at high resolution over both ocean and land. This measurement would address challenges and shortcomings of conventional altimetry (e.g., spatial coverage and resolution) in both oceanographic and hydrologic applications and would enable a wide range of research opportunities in oceanography and land hydrology. The scope of potential operational applications using SWOT data would also be considerable.

2.1 Mission Objectives

SWOT would provide information for researchers and decision makers to address two significant challenges facing our society: freshwater on land. And fine scale ocean processes. For more detailed information on the science objectives, see http://swot.jpl.nasa.gov/science/.

2.1.1 Freshwater on land

The warming of Earth’s climate may profoundly impact the movement of freshwater resources from lakes to rivers to reservoirs and have significant societal impacts.
Without an adequate inventory of Earth’s lakes--only 15 percent of global lakes could be currently measurable from space with one nadir altimeter -- we cannot begin to assess how climate-induced changes to them will impact agriculture, industry and other societally-relevant capacities. Millions of small lakes and rivers have yet to be mapped and monitored for seasonal and annual changes.

Public, freely available stream gauge networks cover only a few river basins. We do not have adequate knowledge of river flow or discharge in most of the global river basins that sustain human needs.

SWOT would inventory a majority of medium to large lakes (approximately 250 meters square and larger) as well as the discharge volumes of rivers (widths greater than approximately 100 meters) -- key measurements that would support scientific research for the following objectives:

- Understanding **the global water cycle on land.**
- Studying the **dynamics of floodplains and wetlands**, which have important impacts on flood control and the balance of ecosystems.
- Providing a **global assessment of water resources**, including transboundary (across international borders) rivers, lake and reservoir storage and river dynamics.

2.1.2 Fine scale ocean processes

The ocean is Earth's largest reservoir of heat and carbon dioxide. Ocean currents are the mechanism responsible for re-distributing this heat and carbon dioxide, and for bringing the climate system into balance to make our planet habitable. Many of these ocean currents are formed over scales too small to be measured globally by current Earth-observing satellites.

Existing technology makes satellites an efficient tool for measuring large-scale changes in the ocean such as El Niño, La Niña and sea level variations. However, current satellites lack the necessary resolution for detecting small-scale ocean currents -- which contain most of the energy from circulation that powers the mixing and transport of water. These factors are important in determining how fast climate is changing.

SWOT would measure sea surface height with sufficient resolution to calculate the speed and direction of ocean currents to address the following objectives:

- **Measure ocean currents and eddies at scales of 15 kilometers (9 miles), which** play a key role in the transport of heat, carbon and nutrients in the ocean. Currents and eddies affect global climate through modulation of sea surface temperature and heat flux, as well as the oceanic uptake of carbon dioxide from the atmosphere. This knowledge could lead to improvements in the ability of computer models to project future climate change.
- Ocean currents and eddies at these short scales are also important to **coastal processes and societal impacts of the ocean on coastal regions, such as navigation, erosion and dispersing pollutants**

2.2 Data Products

Applications using SWOT data would be dependent on the temporal and spatial resolution of the data products developed by the SWOT Science Team and distributed via the partner data providers (e.g., PODAAC for NASA and AVISO for CNES). The spatial resolution of these products would be significantly higher than currently available datasets. SWOT measurements would have spatial resolution of 1 km or better for the low resolution (LR) ocean data and approximately 50 m for the high-resolution (HR) land data.

A table of proposed SWOT science data products would be provided when determined and approved by the SWOT Science Team. Both the content and format details are under

discussion within the Science Definition and the Algorithm Development Teams. The key products would respond to the science requirements of

- Ocean L2: Sea surface height in fixed, geographically located 1 km swath grid with errors, slopes, backscatter (sigma0), range corrections, and geophysical fields (similar to standard altimeter GDRs)
- Hydrology L2 Pixel Cloud: Geolocated pixels with heights, uncertainties, classification (land, water, mixed), flags, range corrections and geophysical fields at the finest scale consistent with reasonable geolocation uncertainty.
- Hydrology L2 Cycle-average Vector Product: Cycle-average water polygons in vector format with locations, heights, slopes, errors, corrections, and geophysical fields.
- Hydrology L2 Enhanced, River Discharge: Reach-averaged river discharge based on a database of river parameters and the measured vector product.

2.2.1 Simulated Data Products

Simulated data products for both hydrology and oceanography are available from simulators developed by the KaRIn system engineering team. The products should be considered notational at this point, but they do contain some key variables from the final products.

2.2.1.1 Hydrology Data Products

Hydrology data products are produced by a simulation software package that is available from JPL (swot.jpl.nasa.gov). A users guide is supplied with the software. The simulator produces interferograms and then uses a height reconstruction program to generate the heights of surface water for a user-supplied digital elevation map (DEM). Models of various error sources are included. Modules for land/water classification and correction of included errors are being developed.

2.2.1.2 Oceanography data products

Simulated oceanography data are available as pass files of sea surface height in swath and most error terms included. Corrections will be included at a later time. The simulated files are available from the NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC, podaac.jpl.nasa.gov) with a users guide.

3. Application Plan Objectives

The SWOT Applications Leads, in collaboration with members of the SWOT Applications Working Group have developed this plan to outline an approach for optimizing the mission assets and outcomes (data, science research) for the benefit of society.

This document outlines a plan for a coordinated and collaborative NASA and CNES applications program for the SWOT mission. This program, funded on the NASA side by NASA's Earth Science Division, Applied Science Program (ASP), and on the French side by the French Investment Program (FIP), is intended to identify, promote and support applied uses of future SWOT and AirSWOT data products by a diverse user community. The path to this end of applied and operational use of the data begins with the SWOT Science Definition Team (SDT). It is the goal of the SWOT Applications Leads to engage key members of the SDT, that is, those particularly interested in applied uses of the data, or those with science objectives that support or involve applied uses or operational agencies, to develop and implement this program. This is a partnership in every sense of the word; it assumes and requires participation, association, and mutual interests of the SWOT Project, the SDT and the SWOT Applications Working Group.

As SWOT is scheduled to launch in late 2020, the Working Group has time to develop a thoughtful, focused plan, which incorporates the best interests of the mission (considering science objectives, project resources, and timelines) with optimal outcomes for societal benefits and possible future operational applications. Important considerations in assessing the utility of the SWOT mission for applications outside of scientific research include: level of data products, ease of access to data, and science outcomes that can support decision-making activities.

This plan is a critical component of the process. It reflects a partnership between the SWOT Applications Working Group, the SDT, and the partner agencies. It will serve to guide the SWOT Project to a user-focused strategy for supporting hydrologic, oceanographic and coastal applications of SWOT and related data products.

Another important component of this effort is the development of a collaborative association with our international partners that, like this plan, will evolve as the mission advances through launch phase, to the development of a time series of data products. We anticipate and look forward to the development of a robust association between the partner agencies on a SWOT applications approach.

4. SWOT Applications Team

4.1 SWOT Applications Leads

The role of these team leads includes oversight of the applications program, facilitation of discussions, tasks, meetings, workshops, etc., as well as development of communication

products, collaborations with SWOT SDT members on Applications-relevant topics and events, and administrative and logistical activities. The SWOT Applications Leads are:

- Margaret Srinivasan, Caltech Jet Propulsion Laboratory
- Craig Peterson, Stennis Space Center
- Alice Andral, CNES
- Michel Dejus, CNES

4.2 SWOT Applications Working Group (SAWG)

The SWOT Applications Working Group (SAWG) is comprised of the Leads along with selected members of the SDT and other interested individuals associated with the Project. The role of this group is to direct the applications science focus and goals, provide links to operational agencies and data users, and to provide focus and guidance on solicitation/funding opportunities.

The SAWG will participate in workshops, provide feedback on data product development with respect to applications, support application development incorporating their relevant science interests, provide feedback to the SWOT mission on applications-relevant issues, assess requirements and benefits of data product, and will help disseminate information about SWOT and applications-relevant data products to broad user and science community. The SAWG is comprised of the following:

- Margaret Srinivasan, Craig Peterson, **NASA Applications Leads**
- Alice Andral, Michel Dejus, **CNES Applications Leads**
- Yi Chao, Remote Sensing Solutions, **U.S. Ocean Science Lead**
- Ed Beighley, Northeastern University, **U.S. Hydrology Science Lead**
- Rosemary Morrow, LEGOS, **CNES Ocean Science Lead**
- Jean-Francois Cretaux, LEGOS, **CNES Hydrology Science Lead**
- Bob Arnone, U. Southern Mississippi at Stennis Space Center
- Sylvain Biancamaria, LEGOS
- Phil Callahan, Caltech Jet Propulsion Laboratory
- Faisal Hossain, University of Washington
- Laurence Houpert, CNES
- Gregg Jacobs, Naval Research Laboratory
- Pierre-Yves Le Traon, Ifremer & Mercator Ocean
- Dennis Lettenmaier, U. Washington
- Delwyn Moller, Remote Sensing Solutions
- Steve Nerem, U. Colorado
- Tamlin Pavelsky, University of North Carolina
- Robert Saint-Jean, Canadian Space Agency

An updated list of the SAWG members can be found at http://swot.jpl.nasa.gov/applications.

5. Strategic Partners

SWOT data products could be integrated with other Earth observations to produce a multi satellite, global information resource for the development and enhancement of water resources management tools and improved understanding of fresh water resources and ocean circulation. We plan to host user workshops to target applications in hydrography and oceanography.

In workshops convened with water resources managers and others responsible for and interested in assessing freshwater transport and disposition, scientists can support the review and assessment of how SWOT and AirSWOT science results can improve on information, products and collaborations for use in decision-making. Collaborations with science team members will also focus on the development of tools that can be used to inform decision makers on:

- River, lake and reservoir levels,
- Flood assessments and potential mitigation measures and water storage,
- Climatic and ecological impacts on water resources
- Water demands for agriculture and agricultural impacts from changes in water resources,
- Sustainable use of water,
- and many other application areas and societal benefits.

In workshops convened with oceanographers, coastal managers and others interested in utilizing the improved resolution of SWOT data to characterize the ocean mesoscale and submesoscale circulation scientists can review and assess how SWOT and AirSWOT science results could improve on information, products and collaborations for use in decision-making. Complementary data from the operational oceanographic altimeters on the TOPEX/Poseidon, Jason series, and European satellite altimeters can also support oceanographic applications of SWOT. Collaborations with science team members will also focus on the development of tools that can be used to inform decision makers on:

- Ocean and Coastal regional circulation modeling and improved storm surge models
- Global and regional sea level change
- Coastal zone management and estuary hydrology, implications on marine life, ecosystems, waste disposal, transportation, and spill mapping
- Improve estimates of the ocean bathymetry
- Mapping the thickness of floating sea ice (ice freeboard)
- Coastal upwelling and cross-shelf transport.

We will take advantage of learning from best practices for other NASA and CNES Earth Science missions that have a heritage for applications – such as Jason-series of ocean altimeter missions, and of data portals such as the NASA Distributed Active Archive Centers (DAACs).

5.1 NASA Applied Science

NASA's Earth science program is dedicated to developing a scientific understanding of Earth as an integrated system, and to understanding responses in that system to natural or human-induced changes. The information provided by a coordinated series of NASA satellite and airborne Earth missions has led to improved prediction of climate, weather, and natural hazards, and provides the basis for many other societal benefits from the long-term global observations of the land surface, biosphere, solid Earth, atmosphere and ocean.

The primary objectives of NASA's Applied Sciences Program (ASP) includes promoting and funding activities to discover and demonstrate the innovative uses and practical benefits of data, scientific knowledge, and technology that stem from NASA's Earth science missions.

NASA ASP is committed to developing and implementing a broad-reaching applications program that includes all early-phase NASA Earth observing satellite missions identified in the Decadal Survey. The NASA SWOT Deputy Program Applications (DPA) Leads act on behalf of the ASP. Lawrence Freidl is the NASA ASP Director, and Bradley Doorn, ASP Water Resources Program Applications Lead, is in charge of the SWOT applications efforts, among other water-focused missions applications efforts. Other NASA ASP programs, such as several capacity building efforts (see below) may present additional opportunities to support and incorporate SWOT applications efforts.

The general goals of the NASA ASP are to discover and demonstrate innovative uses and practical benefits of NASA Earth science data, scientific knowledge, and technology. More specifically, they

- Promote applications research,
- Facilitate development of accessible data products for non-science users,
- Identify and engage a broad community of users to maximize societal benefit of NASA Earth science data, and
- Encourage and enable the applications community to contribute to Earth-observing satellite design and mission planning in the long term.

In order to achieve these goals, NASA ASP funds applied research and applications projects that promote innovation in the use of NASA data for societal benefits. Their focus is on early phase missions identified in the Decadal Survey. In the near-term they are funding the development of applications program for all decadal survey missions. The long-term goal is for Applications to be an integral part of mission planning, development, requirements, and outcomes. The relevant current Applications Focus Areas[2] for NASA Earth science missions include several that are directly relevant to SWOT: disasters, water resources, and ecological forecasting. Future focus areas that SWOT will provide

important inputs to for applications and societal benefits include agriculture, climate, energy, oceans, and weather.

In addition to these elements, NASA ASP supports national and international activities that broaden the range of users applying Earth science data, modeling capabilities, and knowledge in their decision making activities. These "Capacity Building"[3] activities include the programs:

- SERVIR[3] (a Spanish acronym for "Regional Visualization and Monitoring System, which also means, "to serve" in Spanish)
- DEVELOP[4] (a training and development program sponsored by NASA Earth Science Applied Sciences Program)
- Gulf of Mexico Initiative
- Applied remote sensing training

5.2 CNES and the French Investment Program

The French Investment Program (FIP) is the primary driver for the CNES SWOT Applications directives and approach. Innovative and economic aspects of the SWOT mission are highly relevant for the support of the mission by the FIP. Fundamental considerations for the program recognize the high climatic and environmental stakes we face as a global community in the decades to come: How can we improve our models to answer critical questions about current and future trends? What observational accuracies will be required?

For the SWOT oceanography user community, existing elements could be built upon from the framework of conventional altimetry to reach new users with applications in the high-resolution data that SWOT would provide. This will lead to improvement of existing applications and new perspectives especially for coastal areas

SWOT would be the first global survey of Earth's surface water. The hydrology community will turn another corner and much remains to be done.

The pillars of this approach would include:

- Outreach – stemming from the AVISO registered users' database gathering more than 6,000 people, as a tool for operational users to receive information about product parameters and availability. AVISO resources such as RSS feeds, newsletters, IOS/Android apps will be used to reach end-users,
- Existing operational agencies; Mercator Ocean, MyOcean,
- Support of downstream services development.

The goals of the CNES along with the FIP are to:

[3] *http://appliedsciences.nasa.gov/capacitybuilding.html*
[3] *http://www.nasa.gov/mission_pages/servir/index.html*
[4] *http://develop.larc.nasa.gov*

- Develop space applications for the water sector,
- Develop services and technologies based on available data products,
- Build on existing outreach resources, engage and inform stakeholders of SWOT capabilities,
- Define a business model that includes cost reduction for value added products (required by FIP),
- Standardize products and processing to meet users requirements.

5.3 Federal, State, Academic, Industry partnerships

In order to optimize the breadth and reach of the use of SWOT data products, we will collaborate with representatives from Federal, State and local agencies as well as private sector organizations that use satellite remote sensing data, international organizations (our partners and their operational affiliates), and other NASA data users and science team members. We will work towards a program in which access and use of SWOT data products to an engaged applications community would be optimized, for example, through coordination and facilitation of user workshops and meetings (in conjunction with SWOT science team members), and presentations at relevant conferences.

Some of the target partnerships we will pursue and cultivate include;

- Other NASA SMD missions
- USGS
- NOAA; NWS, NESDIS
- USDA
- DOD
- NSGIC
- NRL
- Water security experts (flood forecasting and mitigation organizations; disaster relief organizations, etc.)
- Fish production forecasters
- University partners
- Private sector and NGO organizations (hydroelectric production facilities, global flood insurance and re-insurance industry, etc.)
- Federal, State and local agencies that use satellite remote sensing data
- International organizations (our partners and their operational affiliates
- NASA data users and science team members
- French research institutes: CNRS, IRD, IRSTEA, Meteo-France, IFREMER, INRA,
- French Ministry for Ecology, Sustainable Development and Environment (MEDDE)
- CNES data center Users

5.4 International Partnership and Collaborations

The SWOT mission would continue to coordinate and collaborate with our international partners especially the CSA and the UKSA on assessment of and outreach to user

communities, data product and processing requirements to optimize access, and identifying applications and collaboration opportunities with partners. Other international organizations that may be interested in SWOT data include river basin authorities, committees and organizations, and UN institutions (WMO, FAO, UNEP, World Bank), and others.

5.4.1 Canadian Space Agency (CSA)

Canada is blessed with three oceans, millions of lakes and rivers and needs to understand how to mitigate the societal impacts of ocean levels rise, floods and droughts in these times of climatic changes. In parallel, the growth of economic activities in northern Canada ("The North") is creating requirements for new data necessary for water quantity evaluation and ocean prediction products and services that are used to support emergency preparedness, adaptation to climatic change, search and rescue, the mitigation of oil spills, and at-sea operations such as fisheries and offshore energy.

Participation in the SWOT mission would provide Canada with the capability to close a gap in terms of space data and information for programs and services delivered by two federal departments: Environment Canada (EC) and Department of Fisheries and Oceans (DFO). These departments have well-identified needs for high resolution water level data over Canadian inland waterways and oceans to improve the delivery of their mandates related to key national priorities, such as marine safety and security, water management, environmental monitoring and northern Canada.

The main topics of interest for the Canadian Hydrology Scientists are:

- The Great Lakes watershed;
- The Saint-Laurence River;
- The Peace-Athabasca Delta (PAD) complex;
- The Mackenzie River Delta complex and;
- Assimilation of surface water into climatic models and;

The themes of interest for the Canadian Oceanography Scientists are:

- Sea level variability, ocean currents, fronts, upwelling and productivity;
- Eddies and anomalous features;
- Coupling of SSH information to regional models;
- Study of variations at long time scales;
- Variability in the frequency and strength of mesoscale eddies and;
- Decline and rebound of the Labrador Current.

Through its Grants and Contributions program, the CSA will support academia to offer opportunities to train highly qualified personnel (HQP) in scientific and applications areas that will be important to Canada's development in the decades to come.

5.4.2 United Kingdom Space Agency (UKSA)

The United Kingdom's space policy gives priority to commercial applications, including Earth observations. Talks between CNES and the UKSA have identified areas of cooperation focused on Earth observation missions including SWOT. In January 2014 CNES and UKSA signed a bilateral framework agreement for cooperation in space. One of the points of the arrangement is an initial list of operational projects, which includes SWOT. Additional contributions to the SWOT Project from UKSA will strengthen the international collaborations of the mission.

6. Goals & Methods

The overall objective of the SWOT Applications program is to engage end users and build broad support for SWOT applications through a dynamic and accessible process. The data products that would support hydraulic and hydrologic modeling and water management, and the high-resolution sea surface height products are the link from mission to user. These data products, and models developed from the data, may serve as new tools for many science and applications fields such as river engineering, flood hazard assessment and mitigation[2], drought monitoring, reservoir storage, transboundary river issues, as well as climate studies, marine operations, coastal zone and fisheries management. There are also benefits for informing decision makers on aspects of water demands from agriculture, potential agricultural impacts from water resource changes, and from potential climate impacts on water resources.

Acknowledgement -- Data latency of 60 days will also be difficult for operational agencies. Long lead times will be required for applications involving farming and fishing industries, for example.

The programmatic goals for implementing a successful SWOT applications program include those from the NASA Applied Science Program, those from the CNES, as well as those from the SWOT Project office and the SWOT Applications Working Group.

6.1 SWOT Applications Approach

At the core of this approach to managing applications efforts for the SWOT mission is the imperative for the applications team to work in close association and collaboration with the science and project teams for successful implementation of this program over the life of the mission. This cooperative effort implies support for the applications efforts by the science team, and support of mission science by the applications team. We will foster

[2] http://www.aviso.altimetry.fr/fileadmin/documents/OSTST/2013/posters/Srinivasan_etal_poster.pdf

reciprocal engagement between the mission team and end user based on education of SWOT capabilities and potential uses, and outreach that builds ownership in new ideas and applications involving SWOT data. The goals of this partnership include:

- Promoting the use of SWOT data products and applications-relevant science research outcomes to a community of end-users and decision makers that could incorporate SWOT data products in their operational systems,
- Facilitating feedback between SWOT user communities and the SWOT project,
- Promoting collaborations with varied user groups and communities: hydrology, ocean, ice and drought, agricultural impacts, operational oceanography, and others,
- Designing communication strategies to target and support requirements of the user community.
- Facilitating SWOT and AirSWOT data access to users especially SDT members and early adopters.

Specific objectives for the application team are:

1. In the years prior to launch, develop in-depth understanding of what the SWOT data products would provide, and identify key issues that can maximize their use for applications and characterize the potential value-added for users of the mission datasets. Furthermore, it is imperative to proactively work on the identified issues to maximize the utility of data products to application users. We will accomplish this by active engagement between end users and the SWOT Applications Working Group as well as the SWOT Science Team.
2. After launch, focus on continued engagement with user communities and continued promotion of existing and emerging applications.

In order to achieve these goals, we have organized a team of SDT members, applications collaborators, and partners who will work closely in an advisory and collaborative capacity to target relevant foci, objectives, and approaches. In order to inform a broad user community for SWOT applications, this team will assess current applications benefits and requirements that would come from SWOT data products. We will engage strategic partners, including CNES, CSA, UKSA, other international organizations, Federal agencies (USGS, NOAA), and will identify processes and efforts that will benefit from SWOT.

In order to effectively and efficiently achieve these goals the SWOT Applications Team will:

- Develop a targeted community of end-users (i.e., Early Adopters, discussed in section 8.1) that understand SWOT capabilities and are interested in and capable of using SWOT data products for their applications,
- Target partners who can work with the SWOT project during all the pre-launch period, particularly to assess impacts on their applications during data product

formulation (value-added products, etc,), including enhanced higher level products (level 3, 4) generated by science team members and the user community,

- Incorporate workshops, targeted meetings, email, and personal interactions into planning,
- Write a SWOT Applications Plan (this document) for approval by SWOT Project,
- Engage SDT and future SWOT Science Team to identify and support applications aspects of their work via funding opportunities, and to connect with users and organizations that they interact with,
- Pursue funding opportunities that promote applications with strategic academic, government, and other partners (Applied Science, ROSES, etc.), and
- Seek opportunities to engage in capacity-building activities (i.e., SERVIR, GOMI) via the SDT.

One example of a NASA ASP-funded, SWOT-relevant study was submitted by SDT and SWOT Applications Working Group member, Faisal Hossain (Univ. Washington) and colleagues. Their team is building an altimeter toolbox that will improve the accuracy and reliability of transboundary flood forecasting. The outcome will provide a user-friendly interface for semi-skilled end users. This toolbox will produce a publicly available graphical user interface (GUI) with which any user may extract near real-time river height in any region of interest using the interim GDR Jason-2 data products. The river attributes data toolbox can be expanded to other opportunities focused on end user decision-making and warning dissemination. For example, the toolbox can be tailored according to a generic smartphone application architecture that allows rapid visualization on mobile devices. Furthermore, such applications may facilitate crowd sourcing with which valuable ground validation data for SWOT (in-situ river height, flood extent, rain events, land use etc.) can be affordably obtained from users and communicated to SWOT SDT and Project ream. A prototype of the system is currently being used operationally by water managers in Bangladesh.

A second study is proposed that would support research and implementation tasks related to science data products from AirSWOT campaigns flown beginning in June 2013. The study will focus on the use of remote sensing measurements towards the improved understanding, monitoring and management of estuaries and deltas, with particular emphasis on the Sacramento – San Joaquin Delta Estuary (the Delta) and a coastal region in California.

6.2 Guiding Principles

As the scope and objectives of science-based and societally beneficial applications that may derive from SWOT and AirSWOT are realized, we must keep in mind that there is substantial spatial and temporal variability that must be supported by higher-level data products. The SWOT Applications effort cannot be managed as a homogeneous system if

it is to be effective. Data products, analyses, and models should be documented and transparent so that they can be understood, easily used, and repeated.

7. Applications areas focus

The SWOT science focus has traditionally divided the mission science objectives into two categories: hydrology and oceanography. The science activities and objectives remain defined in this context. In addressing applications and the societal benefits of the SWOT data streams, we will incorporate into our process a synergistic approach that emphasizes a focus on activities with respect to SWOT data measurements, rather than on sub-disciplines. This categorization will identify SWOT-specific and tiered elements with respect to near-term opportunities, such as those that may benefit from AirSWOT, for example, and those that are already using radar altimetry data. The concept is that different applications and users focused on a common activity (e.g., forecasting) will likely share similar data processing tools, use of measurement uncertainties, and needs for specific data latencies. By grouping applications/users by common activities, it will be possible to identify and develop synergies within groups and may ultimately result in a more engaged and diverse user community.

Our broad use of this terminology is briefly described in the following sections.

7.1 Applications focus areas

This approach to addressing applications of mission data products emphasizes the primary sub-disciplines that the proposed SWOT and AirSWOT missions would support; hydrology, and oceanography. Within these sub-disciplines, the applications products may focus on modeling and forecasting, or on planning and engineering, or on management of systems. The emphasis of a given application can include any combination of these aspects.

In order to focus efforts and possible limited resources in applications areas that may optimally support the societal benefits of future SWOT data streams, the following are suggested pillars or foci for SWOT applications;

- Hydrology: developing world water problems, food security (flooding & drought)
- Oceanography: coastal applications (circulation, impacts), marine operations support/open ocean issues
- Climate: regional capabilities, coastal and agricultural impacts

7.2 Activities

For some users it may be preferable to emphasize ‘activities’ rather than sub-disciplines. For example, although two applications may be different (e.g., riverine flood hazard assessment vs. coastal zone management), their use of particular SWOT data products

in terms of processing tools, data uncertainties, and latency may be similar. Grouping these applications may facilitate collaboration and the development tools and models to better utilize potential SWOT data products. Below are three potential activities that are common to many application communities:

- "**Forecasting**" applications may use improved models developed from potential SWOT data to support forecasts of a quantity or system status, for example, reservoir storage next month or an ocean state in two weeks. These forecasts could then be used in decision-making contexts. Important considerations for this perspective include; data latency, observations and uncertainties used by other models.
- "**Planning/Engineering**" applications would utilize the entire time series of SWOT observations. Over the mission life, what range of quantities or system states (e.g., min, max, mean of xyz) are measured by SWOT? At a minimum, future systems should be designed to accommodate the observations. Can a model be developed/calibrated to reproduce the SWOT observations? If so, can it be used to simulate other potential scenarios or conditions? Important considerations for this perspective include; time series data, boundary conditions for other models, and new data for many locations around the globe.
- "**Management**" applications are similar to forecasting in data latency but less focused on modeling of future conditions and more about the current status of systems that will influence decision trees. Important considerations for this perspective include; data latency, observations that may be difficult to obtain from existing data are used to trigger a chain of events.

8. Implementation

The SWOT user engagement approach would include identification of current and potential users, an assessment of current practices on similar and complementary missions (radar altimetry, AirSWOT), and identification of mission data products and product development (including attributes, latency, etc.). This strategy would lead to integration of SWOT and AirSWOT data products into user systems, processes, and decision-making tools.

Phasing of applications activities is aligned with mission phasing as outlined in Appendix A: ‘Applications for SWOT Mission Life Cycles’. Appendix A outlines how the Applications program will grow

Other elements of the implementation strategy will include:

- Broad dissemination of information on SWOT capabilities and data products in order to inform potential users
- Allow and facilitate the access and the use of SWOT data to a broad community

- Identify communities of practice (existing radar altimetry data users, “Early Adopters”) and communities of potential (those unfamiliar with SWOT, but with needs the data products can fulfill) through other altimeter mission contacts and the SWOT science team

8.1 Early Adopters

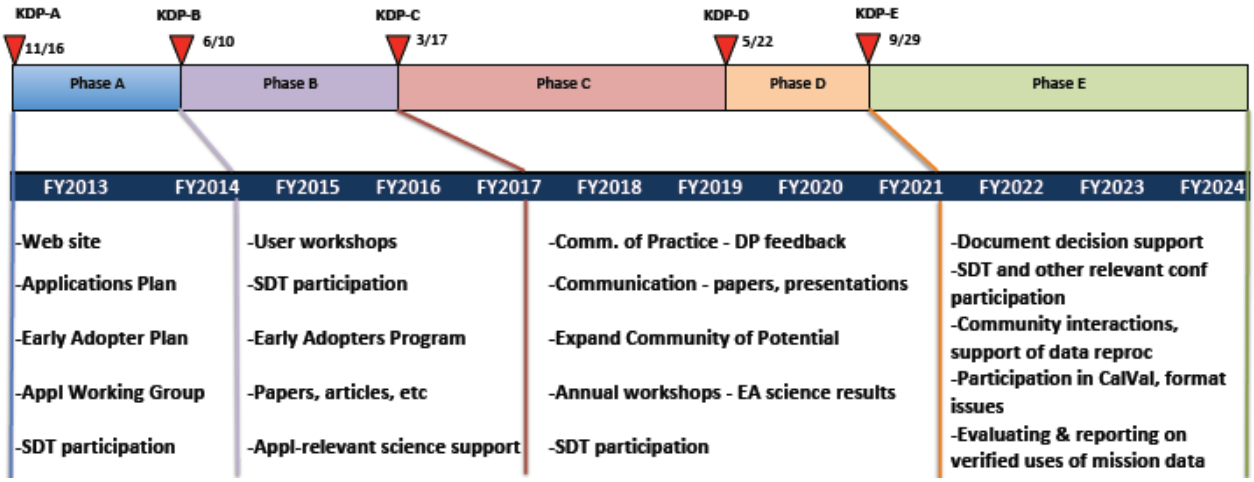
An effort to promote applications research and engage research and users would be developed in order that SWOT data products may be integrated into commercial activities, operational forecasting, and organizational strategies for policy, business and management activities to improve decision-making efforts. The SWOT Applications team will engage Early Adopters early in the development phase of this program in order to fulfill this goal.

SWOT Early Adopters will be groups and individuals who have clearly defined uses, research topics and applications for SWOT data products and information (both hydrologic and oceanographic). This group will have the capacity to extend the use of existing altimetry data sets, use AirSWOT data (as it becomes available), or use simulated data sets that are available from the SWOT Project to enable the integration of SWOT data products into their application or applications-oriented research outcomes. Early Adopters will be selected based on a formalized solicitation from the Project.

Early Adopters agree to;

1. Engage in pre-launch studies and activities that would support a tangible outcome for science or operations for their applications
2. Complete the project with quantitative metrics prior to launch
3. Participate in discussions with the SAWG and provide feedback on data product attributes relevant to their project to increase the applications value and streamline use of data after launch
4. Participate in SWOT applications research, meetings, workshops and related activities

The SWOT Early Adopters approach is described in a separate document, the ‘SWOT Early Adopters Program Guide’, which includes a description of the program, method of soliciting and nominating participants, criteria for selection, and requirements.



SWOT Applications activities relative to mission life cycle. This represents an optimal progression of applications-relevant activities and objectives.

8.2 SWOT Applications Research

Many members of the SWOT science team are strongly engaged in and focused on applications-relevant research and activities. A dynamic collaboration between the SAWG and these science team members is crucial for the success of this program.

The NASA ASP is prepared to fund applications-oriented studies and tool development that would enable access to SWOT data products and applications. This support represents an opportunity for SWOT science team members to implement applications-specific elements in their research efforts. Some examples of approved studies are;

- Development of real-time surface water forecasting tools for large river basins with limited or non-existent in-situ infrastructure. Example: 8 day flood forecasting using altimetry in Bangladesh (2013) and Pakistan, Nepal, India in future. (F. Hossain).
- Support of the AirSWOT Sacramento Bay Delta data product development to improve user access (E. Rodriguez).

The SWOT DPAs will facilitate and support proposals by science team members for applications-focused studies and tools. Other potential studies can include identification of AirSWOT regions for future flight campaigns, studies that will enable easier access to data products, the development of data tools using relevant corollary data that promotes expandability to larger regions or other geographic locations, and improvements in the functioning of a model or actual system as a result of SWOT or AirSWOT measurements or simulated data.

8.3 Synergy with other missions

- Current flight missions (OSTM/Jason-2, GRACE, HY-2A, SARAL-AltiKa, SMOS)
- Decadal Survey missions (SMAP, GRACE-FO, GPM, etc.)
- Future missions (Jason-3, Sentinel 2 and 3, PROBA-V, GRACE 2)

- Applications such as soil humidity or flood forecasting may benefit from synergy with data from radar and VIS/NIR sensors. Landsat series, SPOT, Sentinel, RADARSAT, SMOS, and many more may be considered.

8.4 Communications and Engagement

The SWOT Applications team will act as the primary contact and support for the SWOT applications user community and working group, and will act as liaison to, and work closely with, the science teams.

8.5 SWOT Applications Working Group (SAWG)

The core SWOT Applications Working Group (see section 4.2) will communicate within the team via email (swot.applications.team@jpl.nasa.gov) and at science team meetings and workshops, etc. The following tools will also be used for near and long-term team communications;

- Team telecons established on a regular schedule
- Science meetings: Applications presentations and splinter sessions will be planned at SWOT mission science meetings by members of the SAWG,
- Email communication

The SAWG will function as a community of support, feedback, and collaboration on the implementation of this plan, communications within the SWOT applications user community, and to the Early Adopter program. Outreach activities to science, government, educational, and the general public on the value and utility of the mission will be coordinated with the SAWG to facilitate a clear path for interested users from early mission phases through post launch science and practical uses of the data.

A broad program is planned to engage and maintain continuity with the user community via the SAWG. The following elements will support this effort;

1. SAWG communications: an email listserve will be established for regular communications and to advise of web updates,
2. SWOT Applications web page: (http://swot.jpl.nasa.gov/applications) integrates and highlights all ongoing applications foci and activities. It will include articles, presentations, and posters from meetings. It will be routinely updated and will provide a comprehensive overview of SWOT applications and potential applications for SWOT data. The AVISO+ website will also disseminates information and news about SWOT applications.
3. SWOT Applications Workshops: engage end users and stakeholders through hands-on workshops using simulated SWOT data products (and possibly AirSWOT products) as a way to illustrate, first-hand, the benefits of SWOT. These workshops can also provide mission status and progress to the community of interest, exchange information and capabilities about mission data products and parameters. Workshops will be organized once every one or two years in the early mission phases, up to twice per year as feasible. These events will be organized

to focus on thematic topics (i.e., hydrology or ocean objectives) and will leverage opportunities to combine mission data sets with other complementary missions within Decadal Survey and other current and future missions.

4. SWOT applications-focused sessions, papers and posters at other organized remote sensing and relevant scientific meetings, and participation in other organized hydrology-, ocean- and remote sensing-focused sessions at relevant scientific conferences. These may include;
   - American Geophysical Union (AGU)
   - International Geoscience and Remote Sensing Symposium (IGARSS)
   - European Geosciences Union (EGU)
   - Ocean Surface Topography Science Team (OSTST) meetings
   - Participation in SWOT Project science meetings to share milestones, engage science team members, and solicit partnerships and collaborations,
5. Outreach in more public forums such as blogs, multi-media tutorials, videos, IOS/Android apps and interactive products
6. Submit content (news, articles, announcements, mission or applications status) to newsletters, user forums, and other relevant venues. This may include;
   - EOS Transactions, http://www.agu.org/pubs/eos-news/supplements/
   - NASA & CNES publications (e.g., NASA's Earth Observer newsletter, AVISO newsletter, etc.)

7. The SAWG will seek associations and working relationships with key national and international user groups with established methodologies and relevant topical interests in the use of high-resolution altimetric measurements. These groups may include Mercator, MyOcean, AVISO, USGS, GEOSS, CEOS, and others.

8.6 Assessment

The overall goal of this plan is to engage SWOT end users and build broad support for the use of SWOT data products in science and societally beneficial applications. Deliverables will include successful workshops, papers, posters, and presentations at relevant science venues. The SWOT Applications program will explore optimal ways to adequately assess the integration of SWOT data products (and simulated data products) into relevant user communities relevant to project phasing. Some strategies to evaluate the success of the SWOT Applications Program include;

- Assess the breadth of the SAWG at regular intervals (i.e., bi-annually) before launch, and evaluate growth in the community and diversification of applications,
- Track user community evolution for growth, diversity of application,
- Evaluate pre launch applications investigations and seek formalized feedback from members of the user community on support and relevance of the program,

Identify data gaps and uncertainties so that risk factors can be evaluated.

9. Appendices

9.1 Appendix A. Mapping SWOT Applications to Mission Life Cycles

The optimal progression of applications-relevant activities and objectives are outlined below. Applications activities for SWOT commenced during Phase A of the mission timeline. The following constitutes the planned progression of applications activities for SWOT.

Phase A:

- Web site development
- Applications Strategy and Plan for mission created (this document)
- Initiate Database of user community individuals
- Develop Early Adopter approach, solicitation and a well defined *communities of practice* (both science and policy)
- Formation of the Applications Working Group and designated lead on the Science Definition Team
- Participation in SWOT SDT meetings (Applications Splinters) and relevant conferences (presentations, posters, papers)
- White paper from Phase A lessons learned

Phase B:

- Workshop with targeted science communities to communicate key model, observation and applied science opportunities and requirements.
- Participation in SWOT SDT meetings (Applications Splinters) and relevant conferences (presentations, posters, papers)
- *Early Adopters* identified and cooperative agreements set up to target key integration goals.
- Newsletters, articles and other communication strategies to expand the *community of potential*.

Phase C/D:

- Description and provision of test and cal/val datasets to the community of practice;
- Communication: conference presentations and papers; newsletter and journal articles on user interactions to expand the *community of potential*.
- Annual workshops, focused on applied science results from the Early Adopters;
- Participation in SWOT SDT meetings (Applications Splinters) and relevant conferences (presentations, posters, papers)

Operations:

- Documenting decision support provided by mission data through newsletters, journal articles, conference presentations of applications of data;
- Participation in SWOT Science Team meetings (Applications Splinters) and relevant conferences (presentations, posters, papers)
- Community interaction and support of data reprocessing and improvement
- Participation of calibration/validation of data quality, format, issues;
- Evaluating and reporting on verified uses of mission data

9.2 Appendix B. Acronyms

AGU American Geophysical Union
ASP Applied Science Program (NASA)
Cal/Val Calibration and Validation
CEOS Committee on Earth Observation Satellites
CNES Centre National d'Etudes Spatiales (French National Space Agency)
CNRS National Center for Scientific Research (France)
CSA Canadian Space Agency
DAAC Distributed Active Archive Center
DEM Digital Elevation Model
DFO Department of Fisheries and Oceans (Canada)
DoD Department of Defense
EA Early Adopter
EC Environment Canada
EGU European Geosciences Union
EPO Education and Public Outreach
ESA European Space Agency
EU European Union
FAO Food and Agriculture Organization
FAS USDA Foreign Agriculture Service
FIP French Investment Program (CNES)
GDR Geophysical Data Record
GEOSS Global Earth Observation System of Systems
GOMI Gulf of Mexico Initiative
GPM Global Precipitation Measurement
GRACE Gravity Recovery and Climate Experiment
HQP Highly qualified personnel
HR high resolution
IFREMER French Research Institute for Exploitation of the Sea
IGARSS International Geoscience and Remote Sensing Symposium
INRA French National Institute for Agricultural Research
IRD Institute of Research through Development (France)
IRSTEA National Research Institute of Science and Technology for Environment and Agriculture (France)
JPL Jet Propulsion Laboratory
KaRIN Ka-band Radar Interferometer
L1 Level 1 data product
L2 Level 2 data product
LEGOS Laboratoire d'Etudes en Geophysique et Oceanographie Spatiales
LR Low resolution

MEDDE Ministry for Ecology, Sustainable Development and Environment (France)
NASA National Aeronautics and Space Administration
NESDIS National Environmental Satellite, Data, and Information Service (NOAA)
NGO Non-governmental organization
NOAA National Oceanic and Atmospheric Administration
NRC National Research Council
NRL Navy Research Laboratory
NSGIC National States Geographic Information Council
NWS National Weather Service
OSTM Ocean Surface Topography Mission
OSTST Ocean Surface Topography Science Team
PODAAC Physical Oceanography Distributed Active Archive Center (NASA)
PROBA-V Project for On-Board Autonomy-Vegetation (ESA)
RADARSAT Radar Satellite (Canada)
ROSES Research Opportunities in Space and Earth Science
SARAL-AltiKa Satellite with ARgos and ALtiKa (India and France)
SAWG SWOT Applications Working Group
SDT Science Definition Team
SERVIR Regional Visualization and Monitoring System (acronym from Spanish)
SMD Science Mission Directorate
SMOS Soil Moisture and Ocean Salinity (ESA)
SPOT Satellite for observation of Earth (France)
SSH Sea surface height
SWOT Surface Water and Ocean Topography
UKSA United Kingdom Space Agency
UN United Nations
UNEP United Nations Environmental Program
USAID U.S. Agency for International Development
USDA U.S. Department of Agriculture
USGS U.S. Geological Survey
VIS/NIR Visual/near infrared
WMO World Meteorological Organization